Automatic Approach Seeking Optimal Frequency Modulation Parameters In Chirp Inversion and Chirp Reversal Ultrasound Contrast Imaging

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I – Introduction

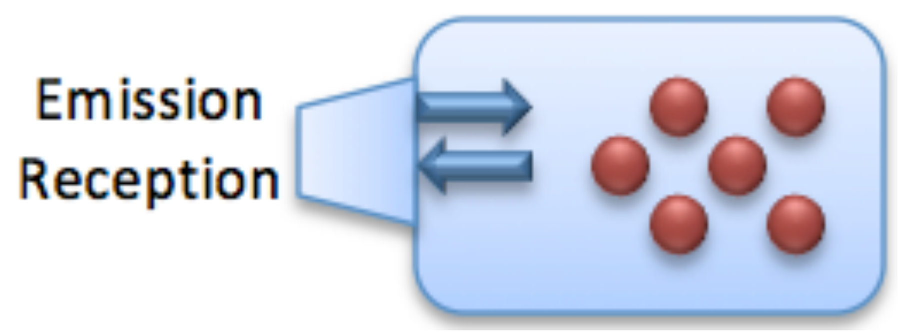
State-of-the art applications involving frequency coded excitations known as chirp excitations, are cutting edge in contrast ultrasound imaging. A question may arise: How does the manufacturer select the frequency modulation parameters of chirp excitations in clinical practice? The present study aims to select, automatically, the optimal frequency modulation parameters of chirp excitations by maximizing the backscattered power using two post-processing techniques: chirp inversion and chirp reversal imaging. Why the power? As the contrast-to-tissue ratio ➚ the power backscattered by microbubbles ➚

$$CTR = \frac{P_{microbubbles}}{P_{tissues}}$$

II – Materials and Methods

Simulated Microbubbles with Matlab

- Air-filled of diameter 5 µm
- Immersed in blood mimicking fluid
- Motion described by Modified Plesset-Rayleigh Differential Equation



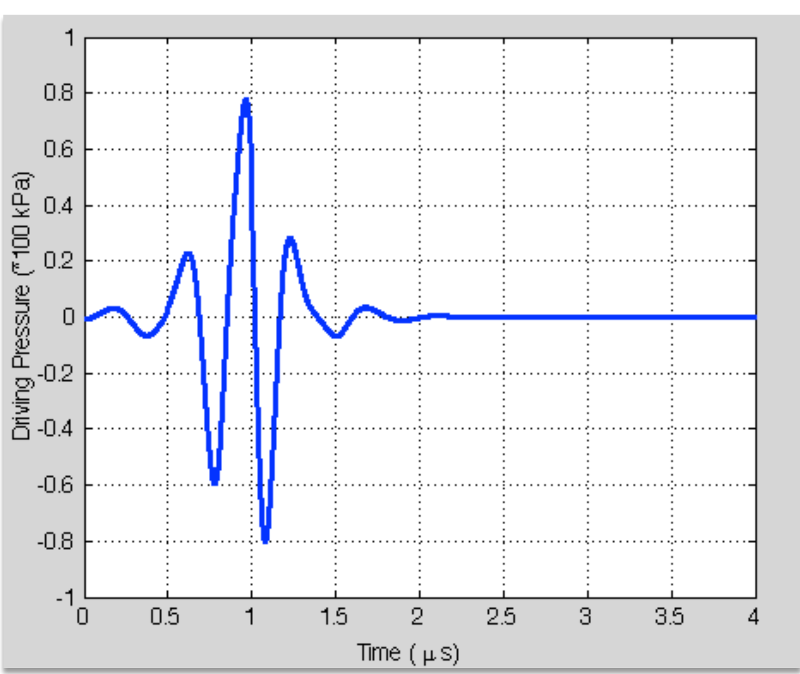
Emission/Reception

- Transducer: Bandwidth 63%

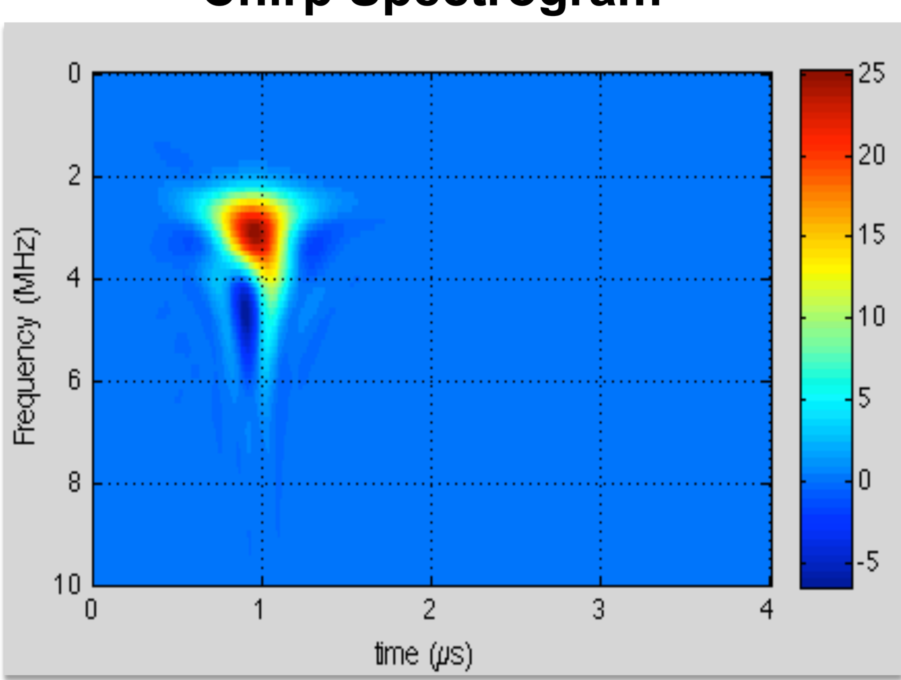
Chirp Excitations

- Frequency modulated → Linear frequency modulation (FM) law
- Initial driving pressure → 100 kPa → NonLinear Response
- Envelope → Gaussian

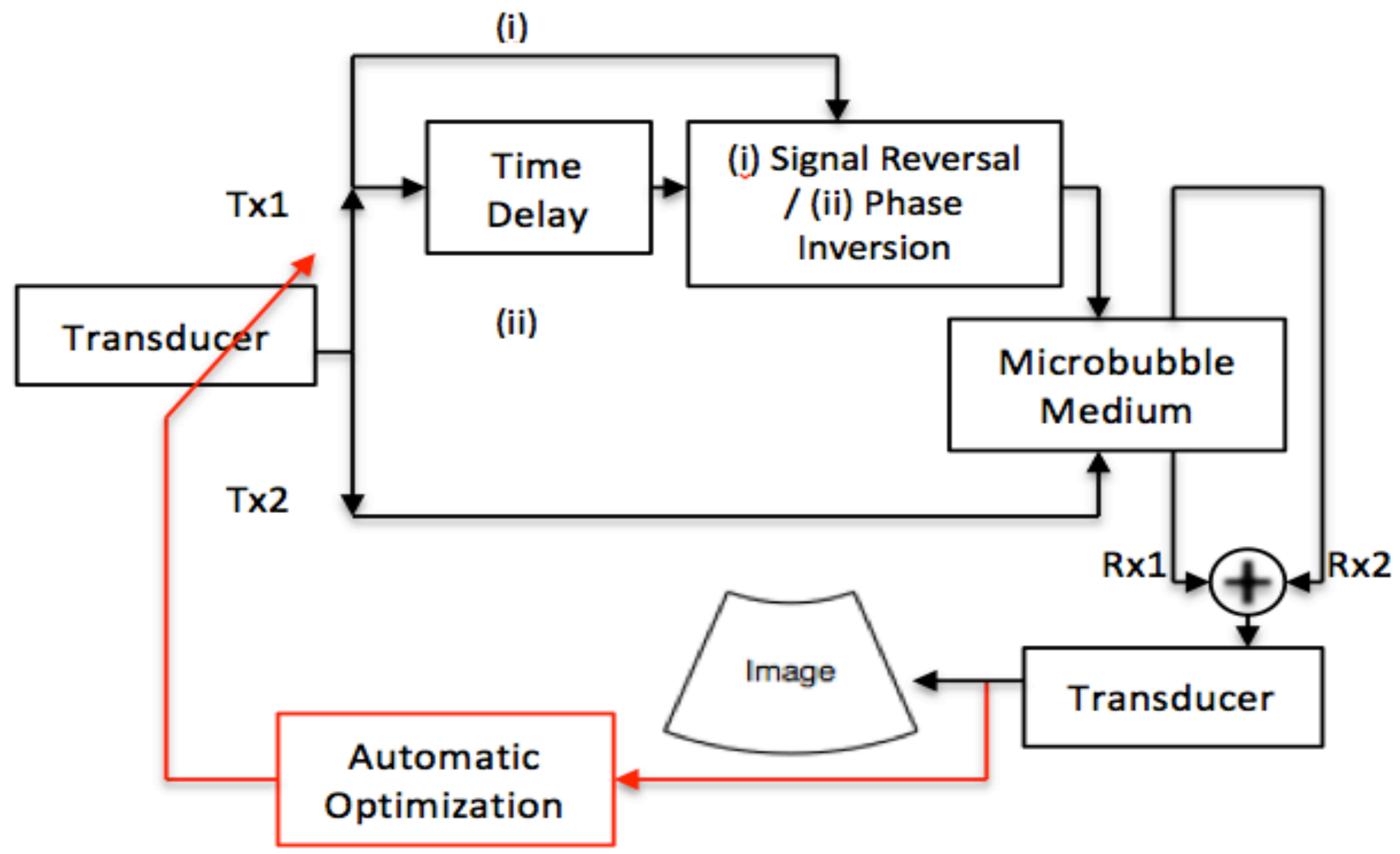
Transmitted Chirp (β=0.03MHz/s, fo=1.5 MHz)



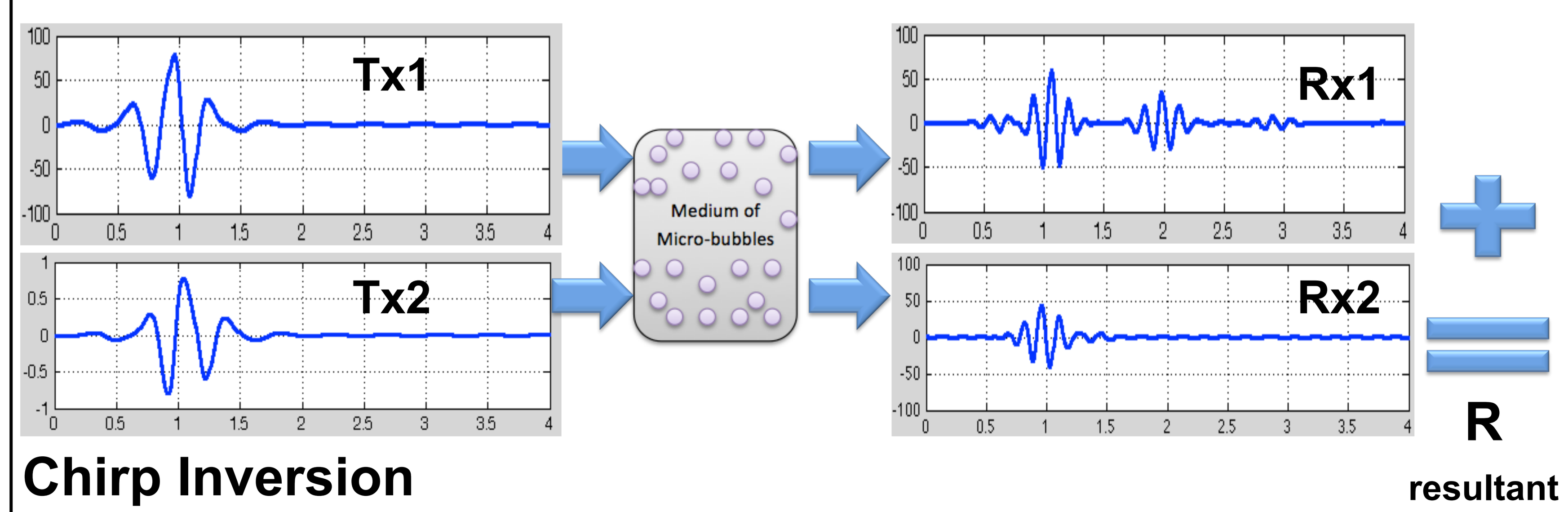
Chirp Spectrogram



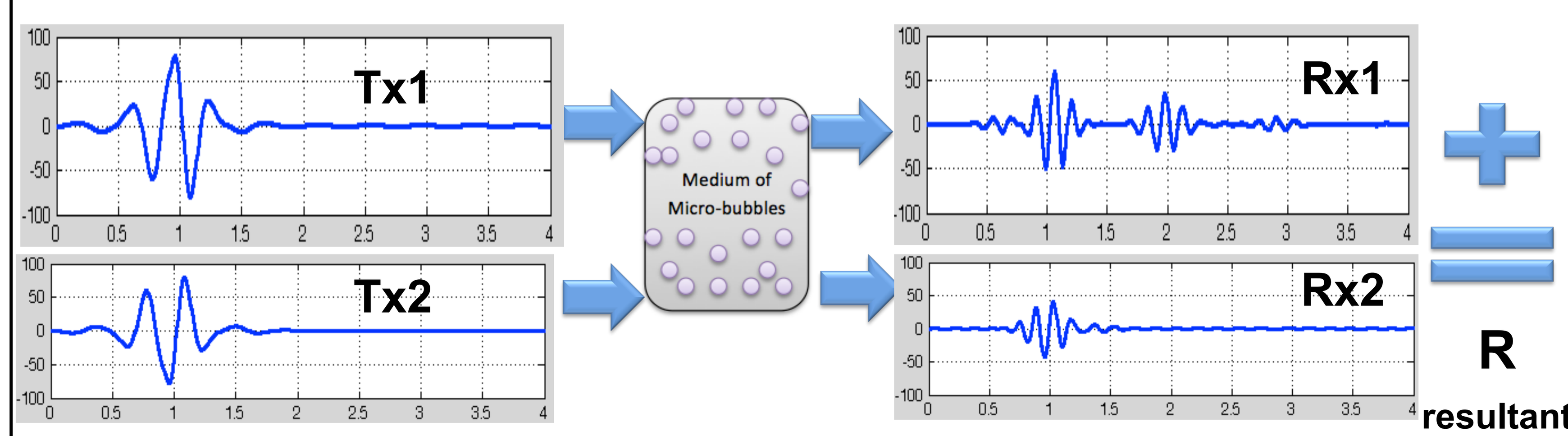
Block Diagram of Chirp Reversal and/or Chirp Inversion post-processing techniques.



Chirp Reversal



Chirp Inversion



Automatic Optimization Approach

- Cost Function J → Resultant Backscattered Power

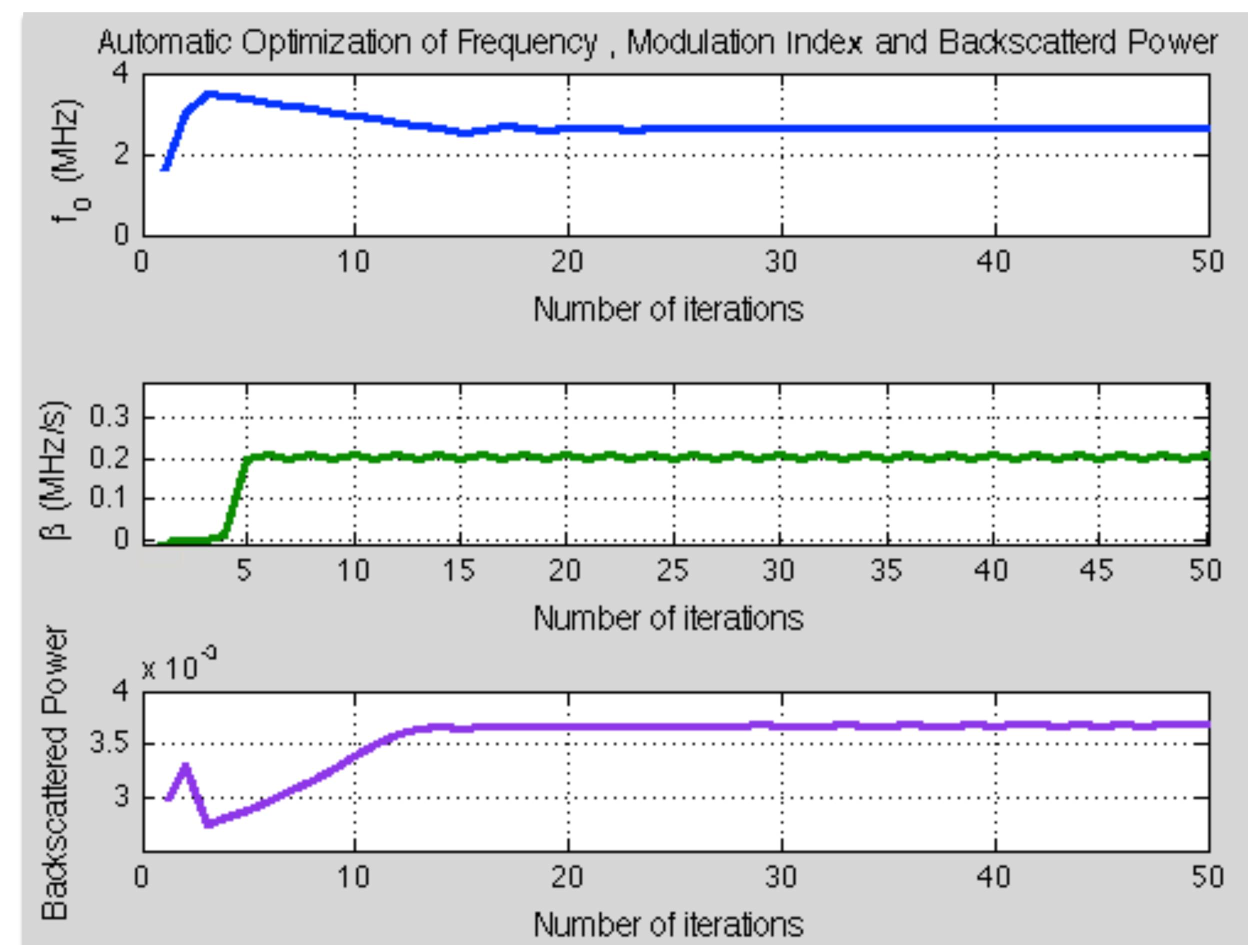
$$w_{k+1} = w_k + \mu_k . \nabla J(w_k)$$

- Automatic Optimization: Maximum Number of iterations k=50

$$\begin{pmatrix} f_{k+1} \\ \beta_{k+1} \end{pmatrix} = \begin{pmatrix} f_k \\ \beta_k \end{pmatrix} + \begin{pmatrix} \mu_{11} & \mu_{12} \\ \mu_{21} & \mu_{22} \end{pmatrix} \times \begin{pmatrix} \nabla_f P \\ \nabla_\beta P \end{pmatrix} \Rightarrow Optimum(f_o, \beta)$$

III – Simulation Results

- Automatic versus Standard chirp reversal (currently available in literature) Gain → 5.4 dB
- Automatic versus Standard chirp inversion Gain → 2.6 dB
- Resultant backscattered power attained after 15 iterations
- Central Transmitted frequency ➚ 1.1 MHz
- Frequency modulation index ➚ 0.23 MHz/s



Processing Technique	Chirp Reversal		Chirp Inversion	
Optimization	Auto.	Stand.	Auto.	Stand.
Modulation Law	Linear FM	Linear FM	Linear FM	Linear FM
Gain (dB)	-24.3	-41.7	-24.5	-31.5
fo (MHz)	2.2	3	2.2	2.75
Beta (MHz/s)	0.23	0.2	0.23	0.1

IV – Conclusion

- Automatic Optimization by chirp reversal/ inversion converged to similar optimized parameters
- Power gain by Chirp Reversal was advantageous over chirp inversion
- Power Gain attained by automatic chirp reversal was significant compared to standard technique
- The proposed Automatic approach may improve CTR of Ultrasound Images so we tend to validate it by experiment

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